
Technical Challenges in the Evolution of Flexible CIGS Photovoltaics for Terrestrial Applications to a Viable Space Product

Space Power Workshop 2000

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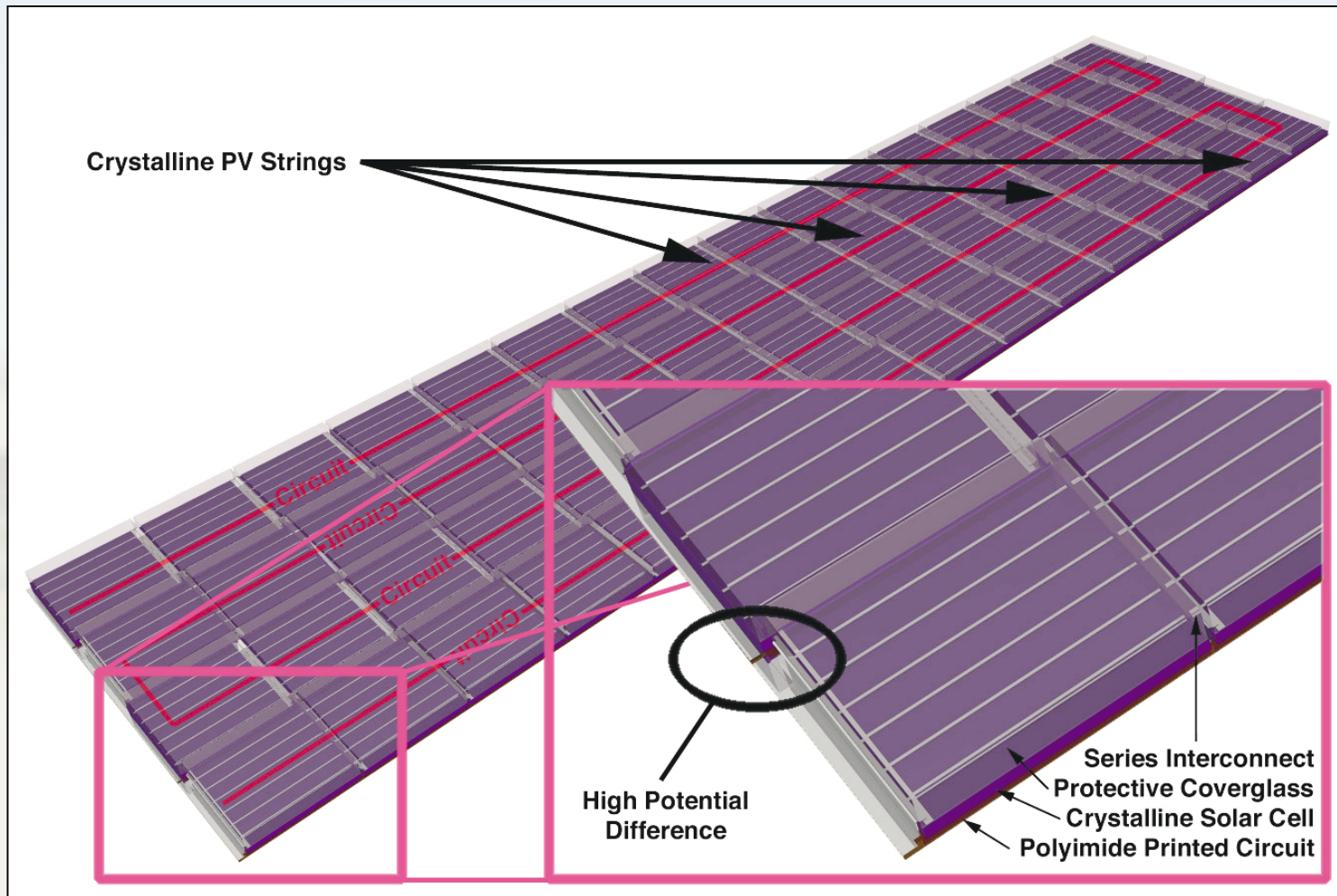


Programs/Sponsorship

- **Flexible CIGS Manufacturing**
 - DARPA “Vapor Phase Manufacturing of Flexible Thin-Film CIS Photovoltaics”, DARPA agreement No. MDA972-95-3-0036
- **High-Voltage Array Development**
 - NASA GRC High Voltage Array, NAS3-99102 SBIR Phase II
- **Multijunction Devices**
 - F29601-98-C0220 (AFRL/Space Vehicles Directorate)
 - 70NANB8H4070 (ATP/NIST)
- **Diode Protection**
 - BMDO F29601-99-C-0152, Monolithically-Integrated Diode Protection
- **Internal Funding at Both ITN/ES and GSE, LLC for Space Products**

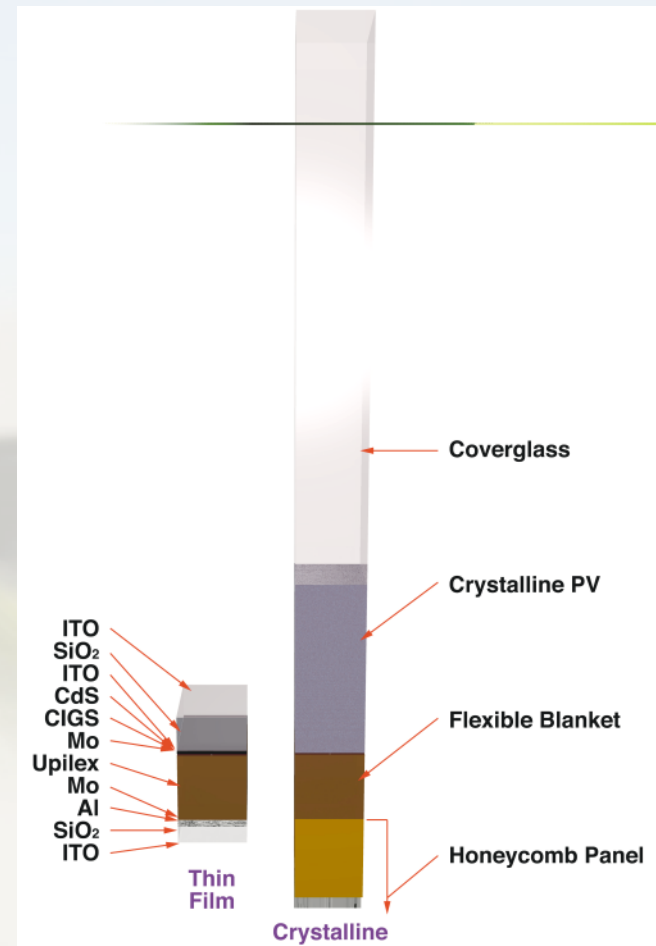


Conventional Spacecraft Crystalline PV Arrays



Advantage of Flexible CIGS Product

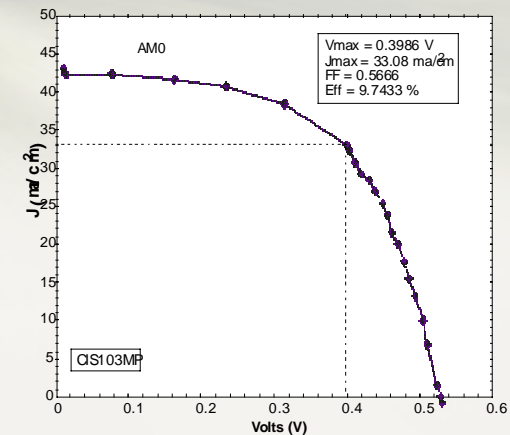
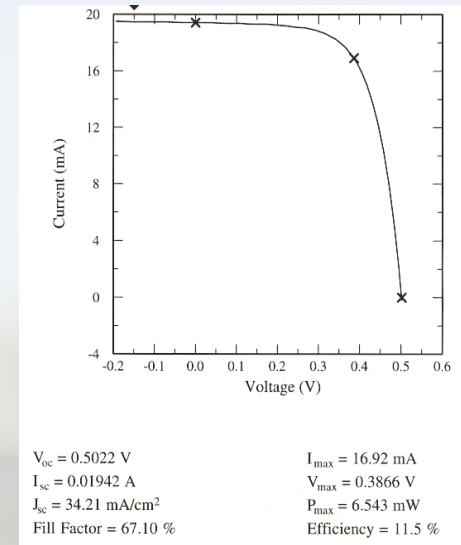
- **Negligible Profile Change Allows for Complete Encapsulation of PV**
 - **Crystalline Technology Has Tremendous Profile Change, Making Electrical Isolation of Array Virtually Impossible**
- **Electrical Isolation of PV Allows for Conductive Discharge Layer to Eliminate Static Buildup**
 - **Crystalline Technology Would Need to Ground the Surface of Each Cell Stack, Increasing Cost and Decreasing Reliability**



Cell I-V Characteristics

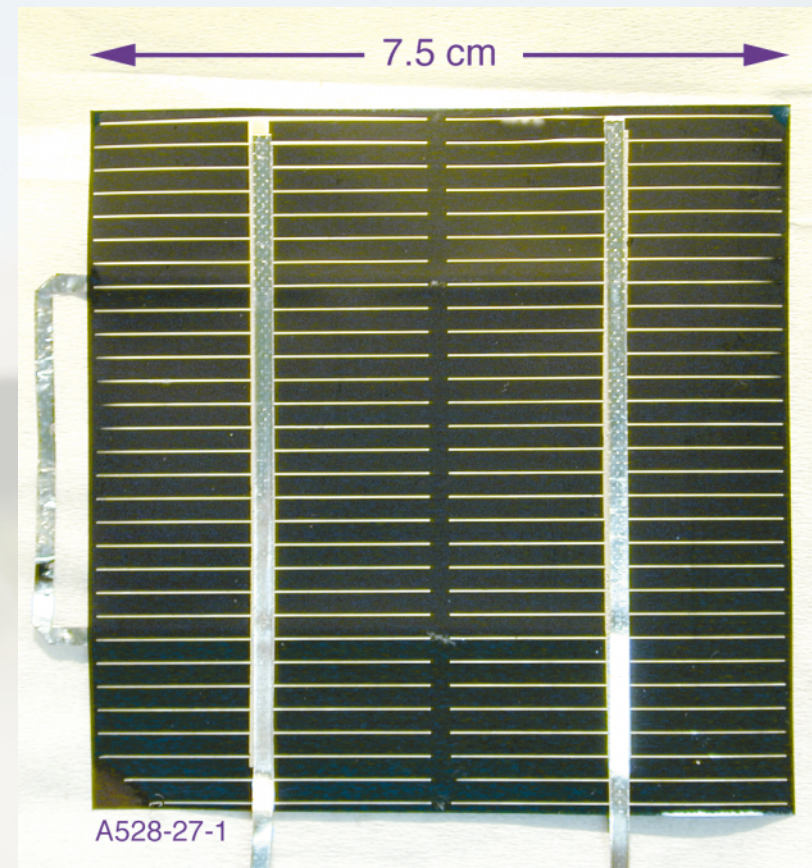
- **Achieving Good Efficiencies**
 - Up to 11% for Roll Coated CIGS with laboratory-based CdS and ZnO Window Layers
 - Many over 10% using all Roll-to-Roll Processes
 - » Production Based Equipment
 - » Production Based Speeds
 - » Averaging over 8%
 - Good AMO Performance
 - » Need to Develop Database with 3 sigma limits for Flexible CIGS

All Roll-to-Roll In GSE Production-Based Equipment at Production Rates



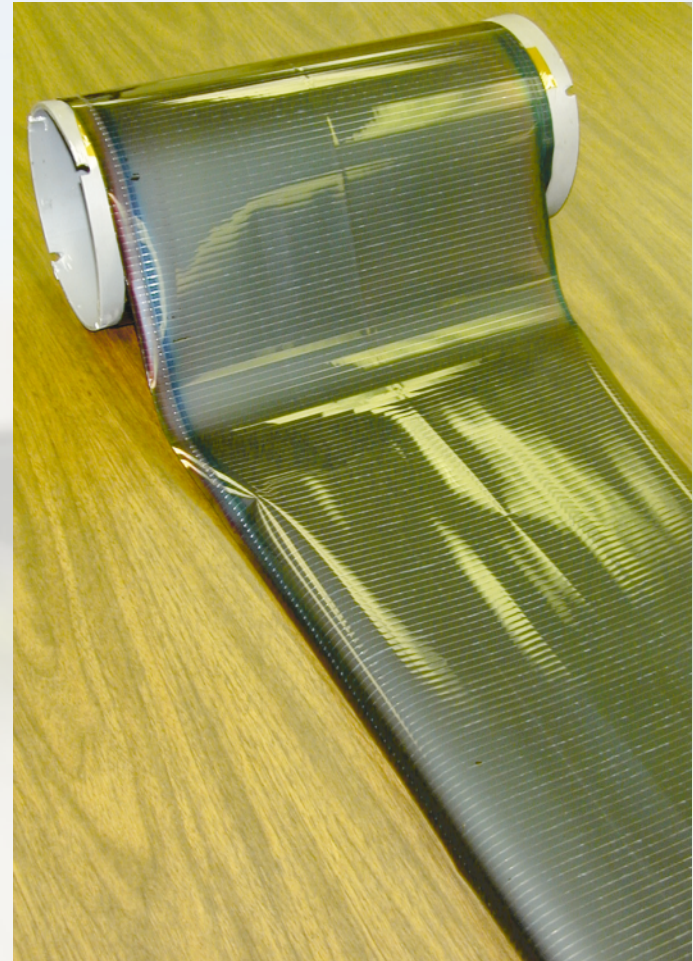
Current GSE Products for Space

- **Flexible CIGS on Stainless Steel Substrate**
 - **Advantages**
 - » **More Mature Technology**
 - » **Higher Process Temperature Limit**
 - » **Demonstrate Higher Efficiency**
 - **Disadvantages**
 - » **Conductive Substrate Eliminates Monolithic Integration**
 - » **Possible Weight Hit Unless Thin Foils are Used**
 - » **Must Utilize “Conventional” Integration**
 - » **More Difficult to Encapsulate**



Current GSE Products for Space (cont)

- **Flexible CIGS on Polyimide Substrate**
 - **Advantages**
 - » **Insulating Substrate Allows Monolithic Integration**
 - » **Dramatically Fewer Interconnects**
 - » **Reduced Installation Cost**
 - » **Higher Voltage String in Smaller Space**
 - » **Low-Profile Change Between Cells**
 - » **Easier to Encapsulate**
 - **Disadvantage**
 - » **Technology Behind Metal Foil Substrate**
 - » **Limited Process Temperature**
 - » **Lower Efficiency**



Space vs. Terrestrial CIGS Solar Arrays

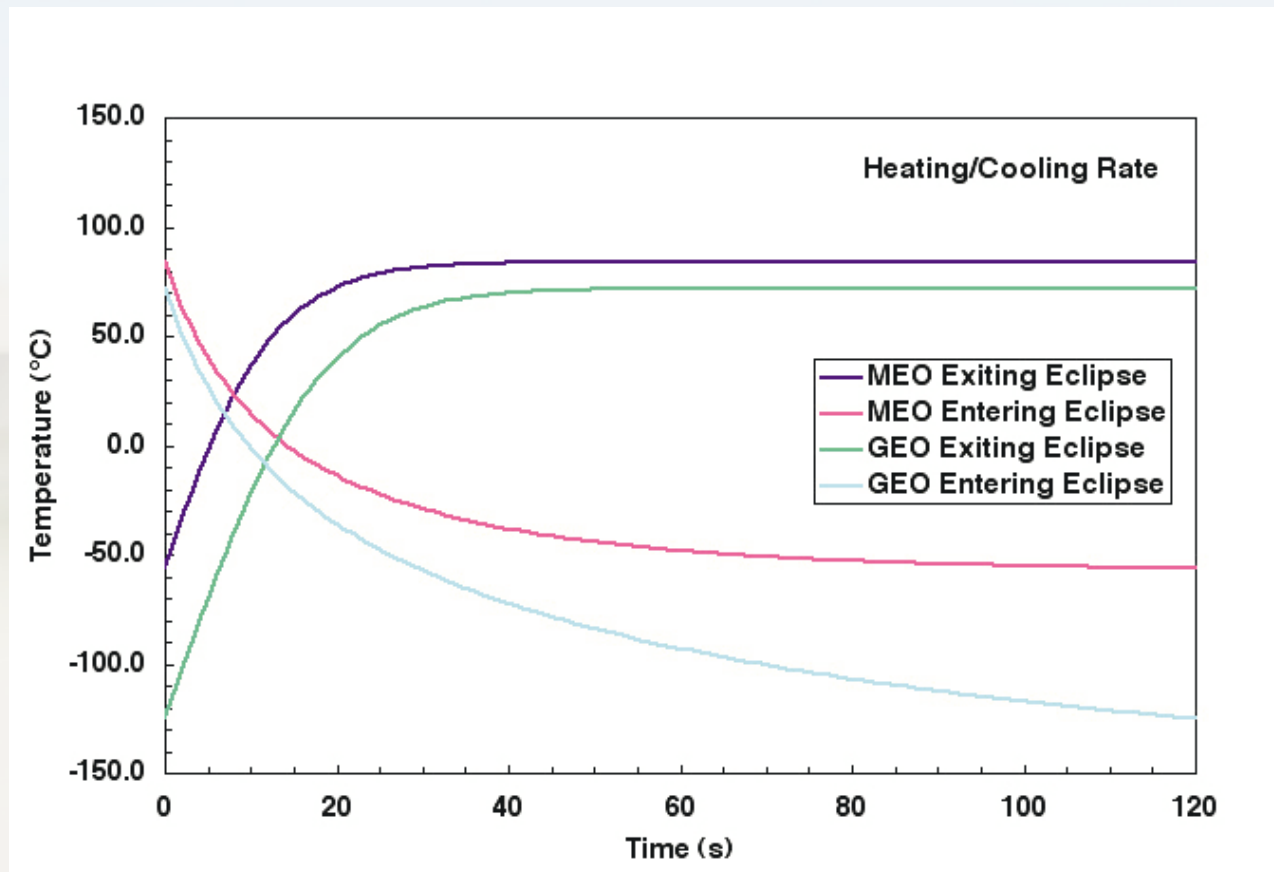
- **Key Differences in All Deposition Operations and Finishing**
 - **Optimize Deposition Operations to Achieve Best Efficiency**
 - » **Use Best Portion of the Web (Decreasing Yield)**
 - **Requires Extra Deposition Operations for Space Durability**

Layer	Terrestrial	Space
Mo Back Contact	<ul style="list-style-type: none"> - 0.4 microns, 1 to 2 ohms/sq. - ~1% I^2R Resistive Losses 	<ul style="list-style-type: none"> - 0.8 to 1.0 microns, 0.1 to 0.5 ohms/sq. - ~1% I^2R Resistive Losses
CIGS Absorber	<ul style="list-style-type: none"> - Maximize Rate at Expense Of Slight Decrease in Efficiency (12 to 24-in/min) 	<ul style="list-style-type: none"> - Slow Rate to Optimize Efficiency - Use Best (Central Section of Web) ® Decreased Yield
CdS Window	0.06 to 0.08 microns, Loose some Short wavelength current but ensure good yield	Optimize to 0.04 microns to minimize short wavelength current losses ® Likely Decrease Yield
TCO Front Contact	0.6 microns to achieve 10 to 30 ohm/sq ~10 % I^2R Resistive Losses	1 to 1.5 microns to achieve 5 to 10 ohm/sq < 5% I^2R Resistive Losses
Finishing	EVA/Tefzel Industrial Standard	Combination of Extra Coatings for Radiation Protection, Thermal Control, and Charge Control



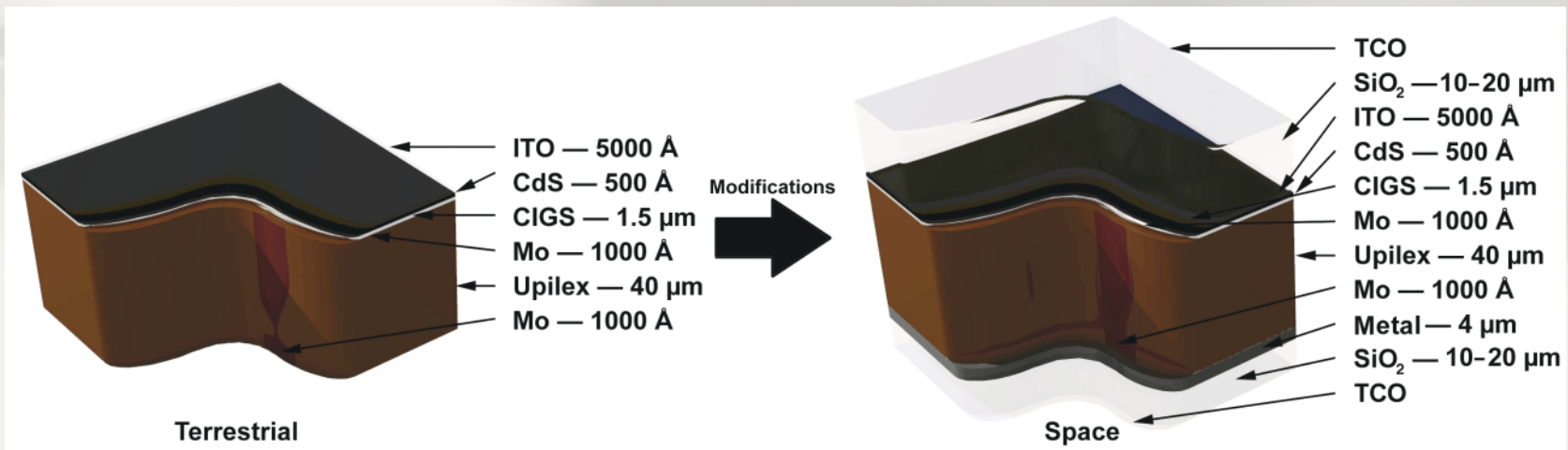
Thermal Issues in Space

- Challenging Heating and Cooling Rates
- CIGS Requires a Nominal Emittance of 0.8 for Reasonable Thermal Environment



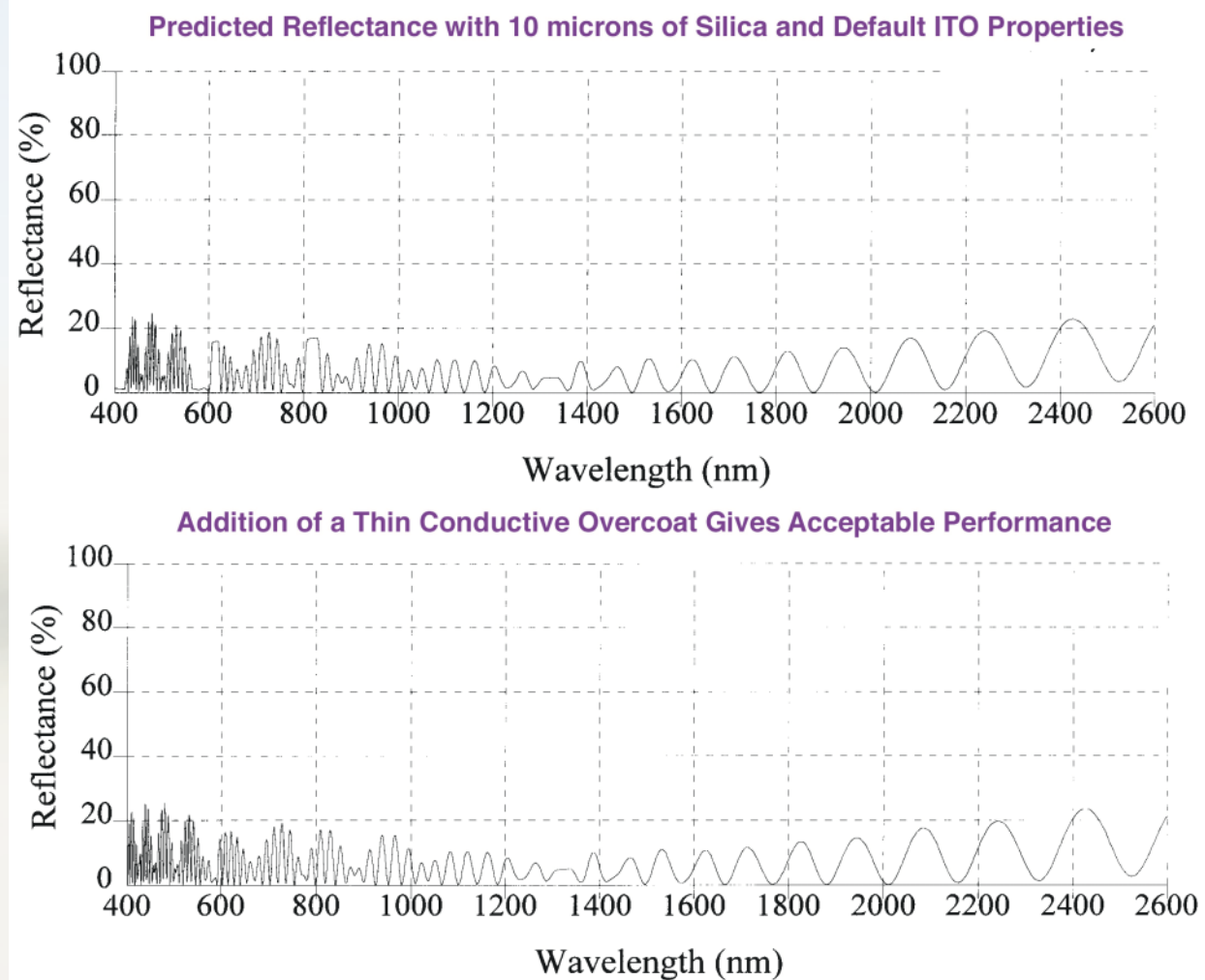
Coatings from the HVASA Program

- Identified and Demonstrated Coatings Required for Space Applications
 - Conductive Film for Charge Dissipation
 - Thermal Control/Radiation Protection Coating
- Demonstrated High-Voltage String with Zero Net Current Design
 - Ideal for All Large Array Applications
 - Reduced Harnessing Weight by Using Back of Module as Conductor



Optical Performance of Thin-Film Devices

- **Addition of Silica and Transparent Conductive Film**



Emittance of Various CIGS Films

- Addition of Silica Increases Emittance Significantly

Sample #	Description	Measured Normal Emittance	Estimated Hemispherical Emittance
990707A2	CIGS/ITO + 10 microns Silica	0.75	0.72
990707A6	CIGS/ITO	0.22	0.24
990701M1	Upilex/Mo + 10 microns Silica	0.70	0.68
981102A1	Al foil + 10 microns Silica	0.68	0.67
981003U2	50 micron Bare Upilex U50S, backed w/Al plate	0.79	0.76
981003U1	As above + 10 microns Silica	0.83	0.79



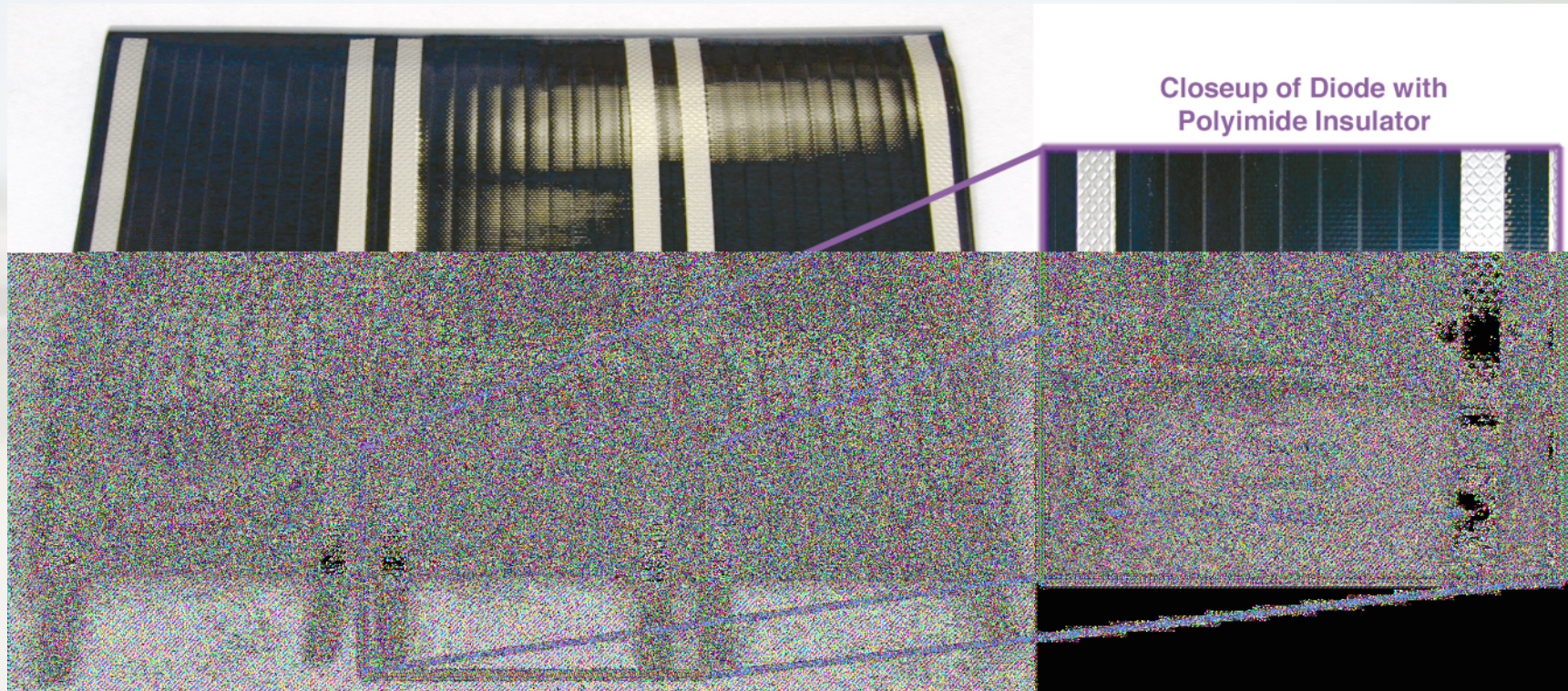
Flexible CIGS Metal Substrate Array

- **Metallic Substrate Cells Interconnected in Series via Comb Contacts**
 - **Optimized Performance by Minimizing Losses with Various Geometries**



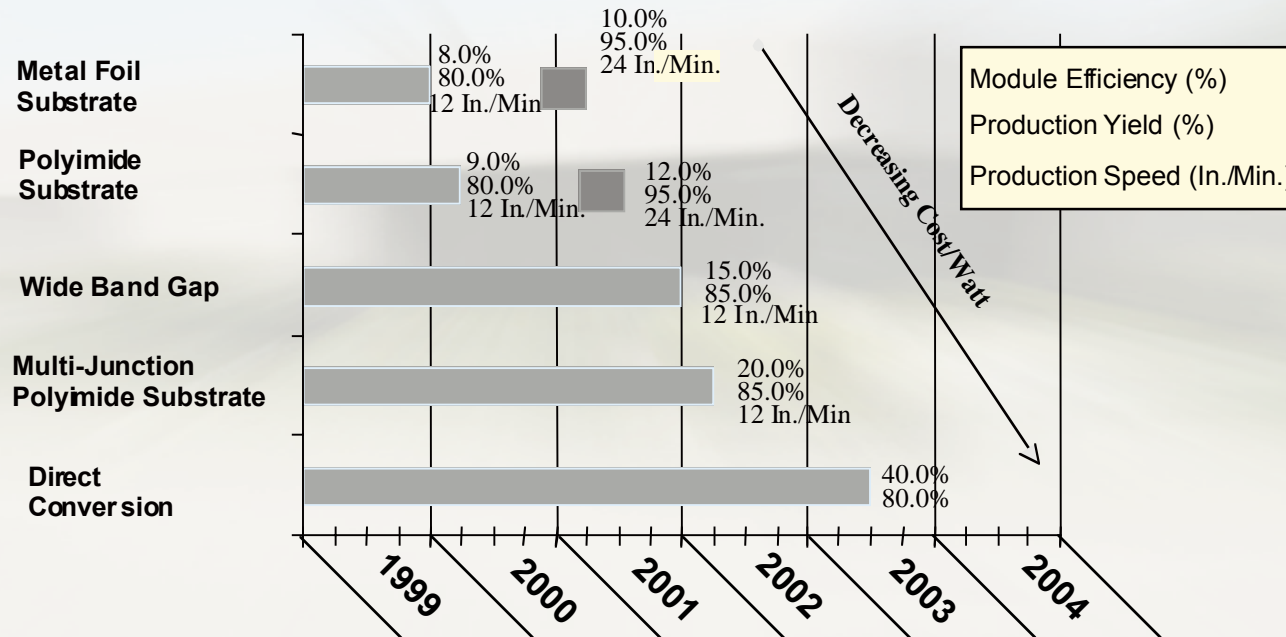
Flexible CIGS Polyimide Substrate Test Article

- Demonstrates Monolithically-Integrated Diode Protection
 - Opaque Coating Not Included for Clarity



Pathway To Higher Efficiency

- **With Baseline Process in Hand (7 to 10%), Further Increase in Efficiency Achieved By Optimizing Individual Layers**
 - Minimizing Resistance in Front and Back Contact
 - Maximize Transmission in the Front Contact
 - Minimizing Sputtering Damage
 - Optimizing Ga Profile in CIGS
 - Optimize CdS Thickness

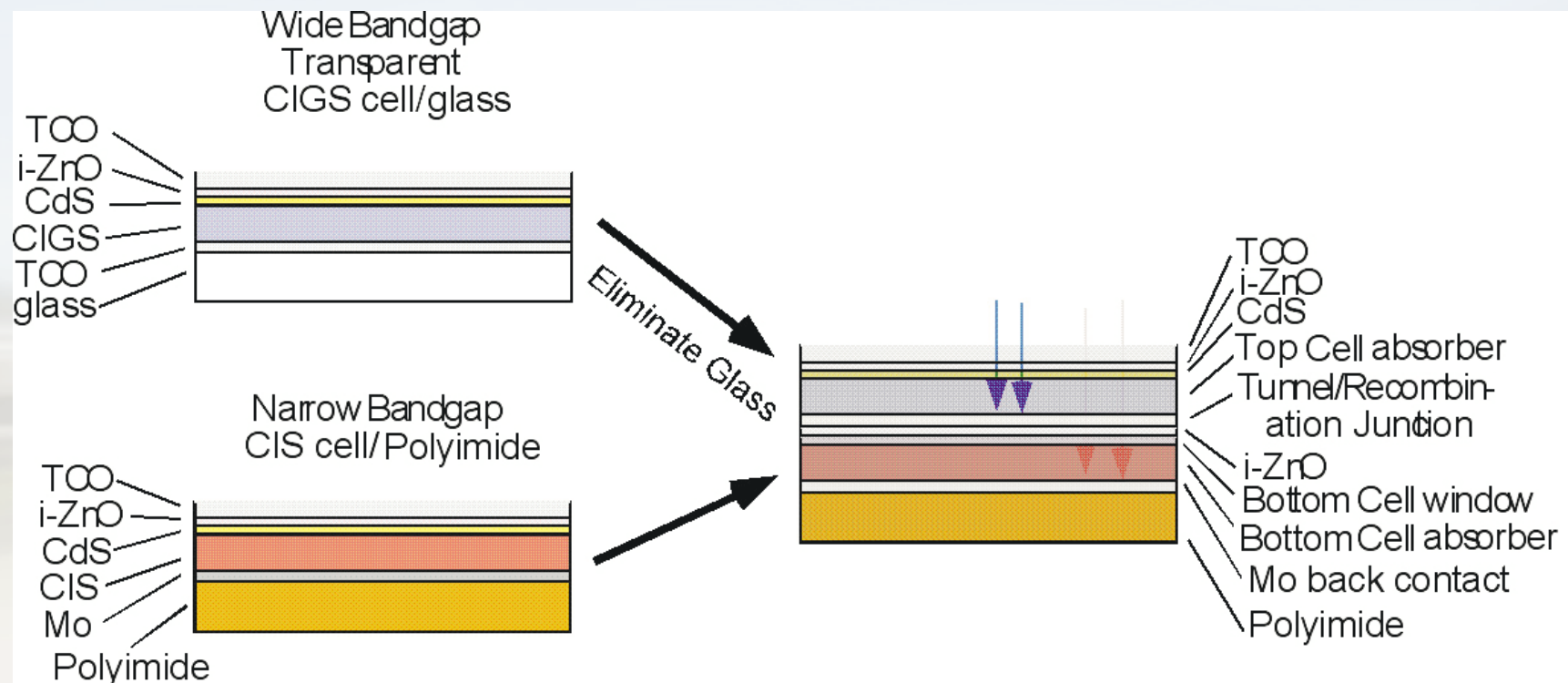


- **After Single Junction is Optimized**
 - » **Multi-Junction (AFSA-II, Air Force Program)**



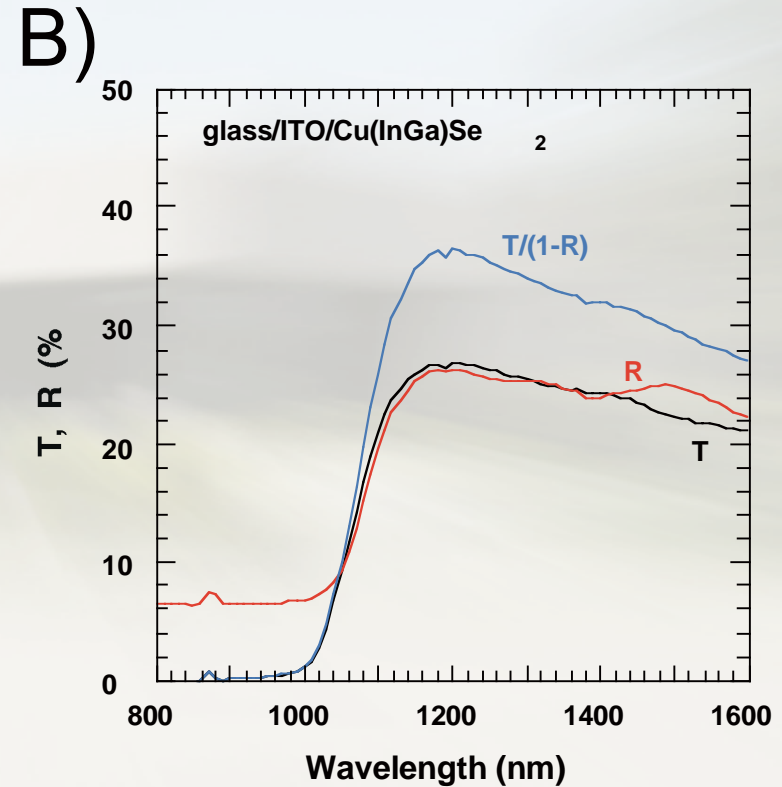
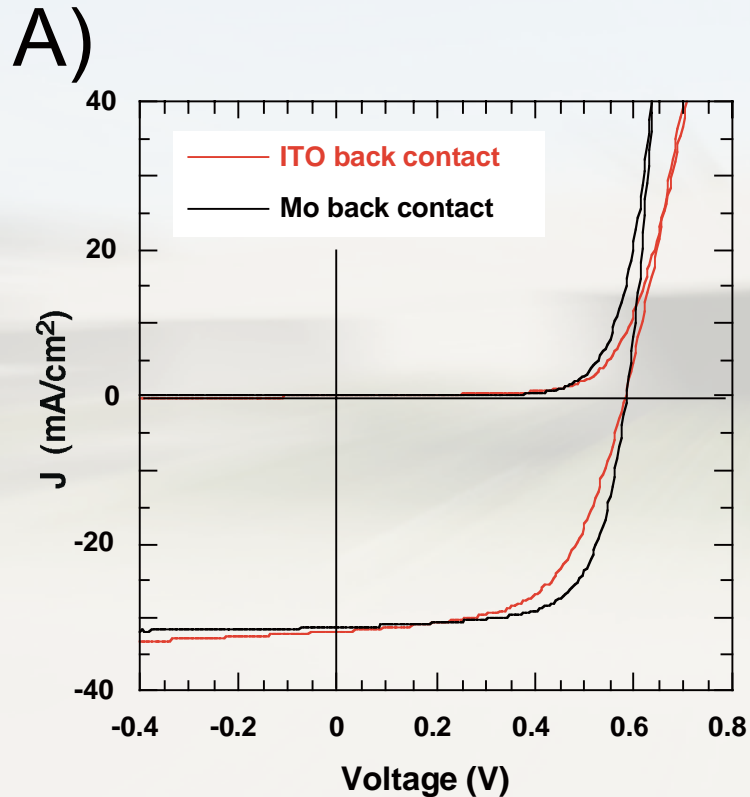
Multijunction Approach

- Tandem CIS Device



Multijunction Development

- A) I-V and B) optical transmission and reflection data from CIGS devices deposited on Mo/glass and ITO/glass substrates during AFSA Phase I.



Multijunction Development

Substrate/ Back contact	Voc (V)	Jsc (mA/cm ²)	FF (%)	AM1.5G Efficiency (%)
Mo/glass	0.587	31.4	67.7	12.5
ITO/glass	0.585	32.0	58.4	10.9



Summary

- **Thin-Film CIGS Flexible Devices are Promising Technologies for Future Space Missions**
- **Significant Work in Progress to Develop Flexible CIGS for Space Applications**
 - **Processing**
 - **Integration**
 - **Protection**
 - **Performance**
- **More Work to be Performed to Ensure Product Reliability and to Establish Control Limits of a Production Device**

